

Changes in Characteristics of United States Snowfall over the Last Half of the 20th Century

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Background

Large portions of the mid- and high-latitude NH land areas show increasing precip. over last half of the 20th century (e.g., Karl et al. 1993, 1998; Groisman et al. 1993).

In the U.S. there has also been an increase in “extreme” precip. events (Karl et al., 1998).

However, NH annual snow-cover extent has decreased by ~10% since 1966 (IPCC 2001), mainly due to spring and summer decreases since the mid-1980s over Eurasia and North America (Robinson, 1997, 1999).

IPCC (2001) points out that relatively few studies of *snowfall* trends across the globe have been undertaken.

We decided to study U.S. snowfall variations due to ready access to high-quality data.

Some previous U.S. snowfall findings include:

- Increased inter-annual variability in nationally averaged snowfall over the 1970s and 1980s (Karl et al. 1993)

- Increased snowfall in the central U.S. over the 20th century (Hughes and Robinson, 1996)

- Increased snowfall in recent decades to the lee of the Great Lakes relative to the early 20th century (Leathers and Ellis, 1996)

We will expand on these earlier findings by examining some additional snowfall variables and using the latest data available.

Data

United States Historical Climatology Network daily data (Easterling et al. 1999), housed at CDIAC (includes snowfall for 1062 stations)

Analysis Procedure

Stations chosen based on location and quality of record.

Restricted to those stations north of 35 °N.

Many stations in the currently available database only have digitized records from 1948 onward.

Examined those stations' completeness of record from 1948–2001.

Required stations to have no more than 4 years in which *any* daily snowfall amounts were missing from October–May (our chosen “snowfall season”).

217 stations chosen for analysis over “winters” of 1948/49–2000/01.

Variables Examined:

Snow days, i.e., number of days exceeding a trace (0.1")

Snowfall amount

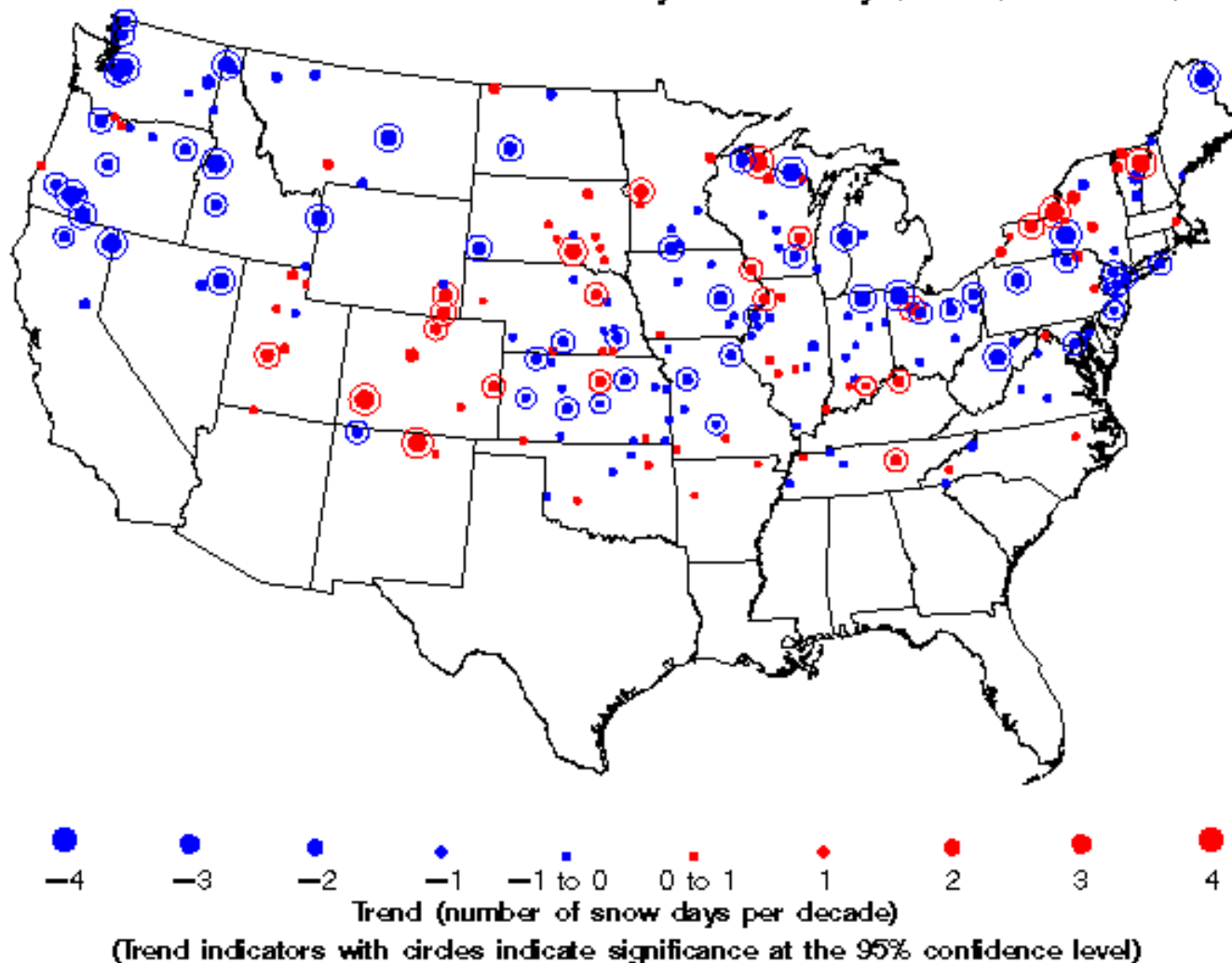
Percentage of annual precipitation resulting from snowfall

First and last day of snowfall; length of snowfall season

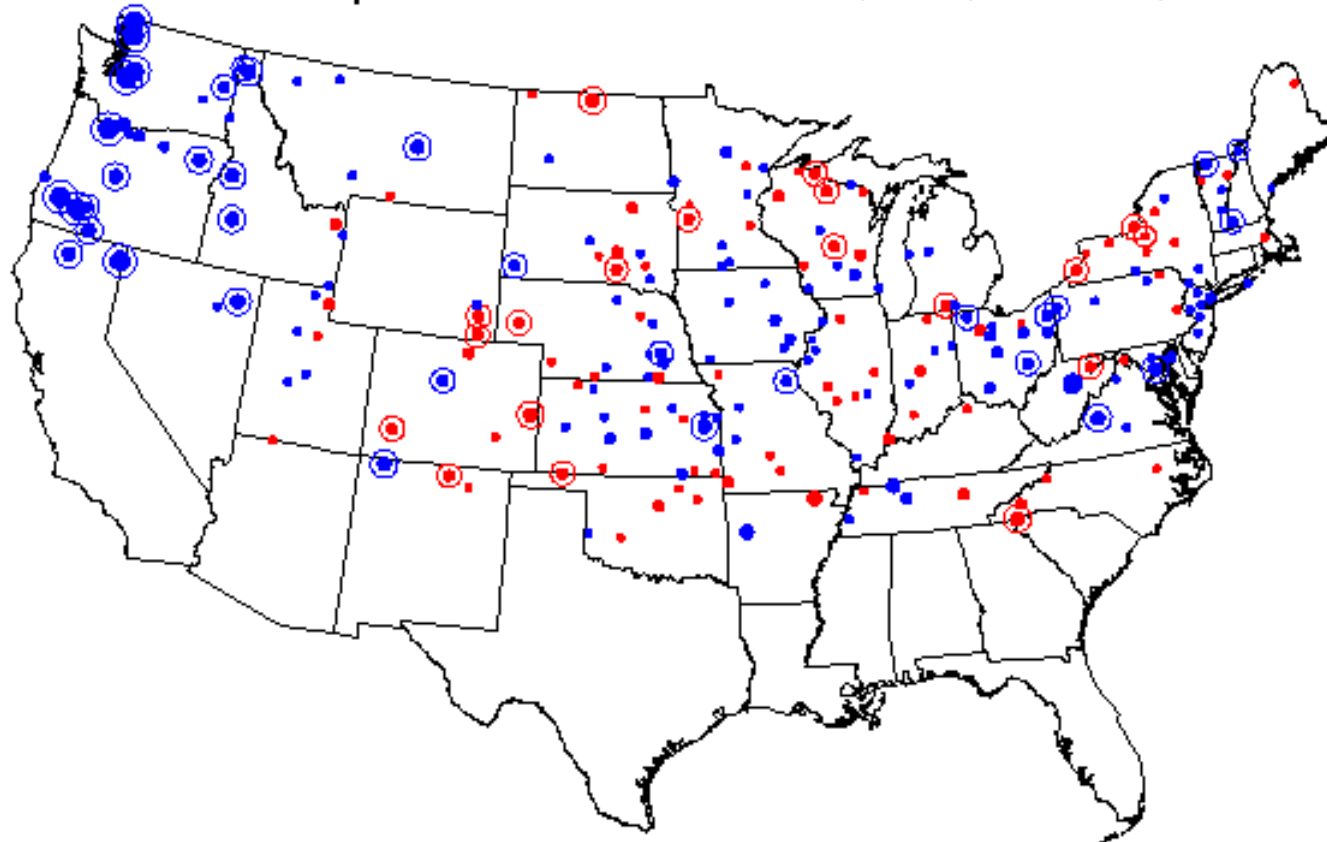
Mean temperature of “snow season” and on snowfall days

Changes in several snowfall variables for snowfall percentiles

Trends in the Number of Oct—May Snow Days, 1948/49—2000/01



Trends in percent of normal snowfall, 1948/49–2000/01

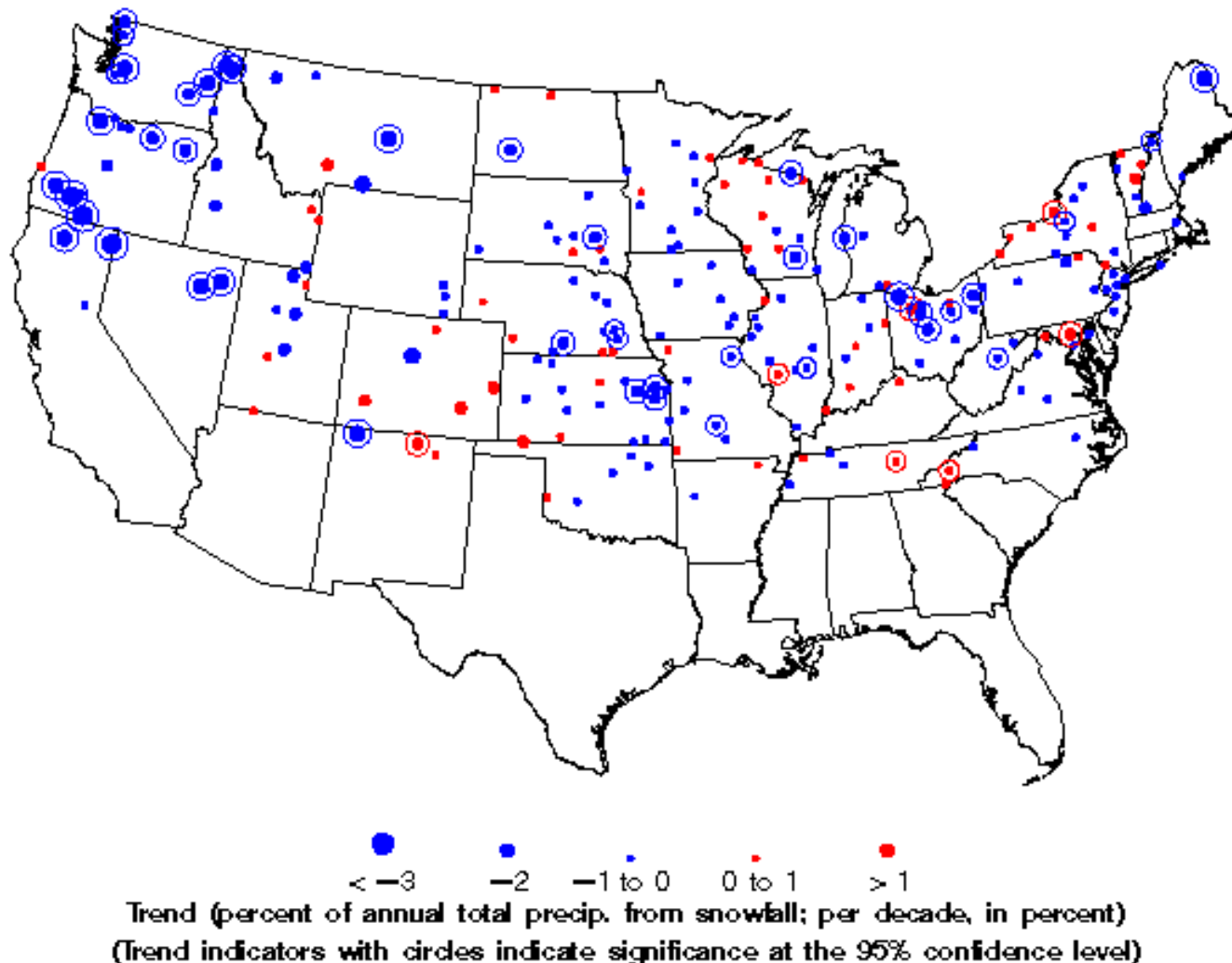


● -90 ● -60 ● -30 ● -30 to 0 ● 0 to 30 ● 30 ● 60 ● 90

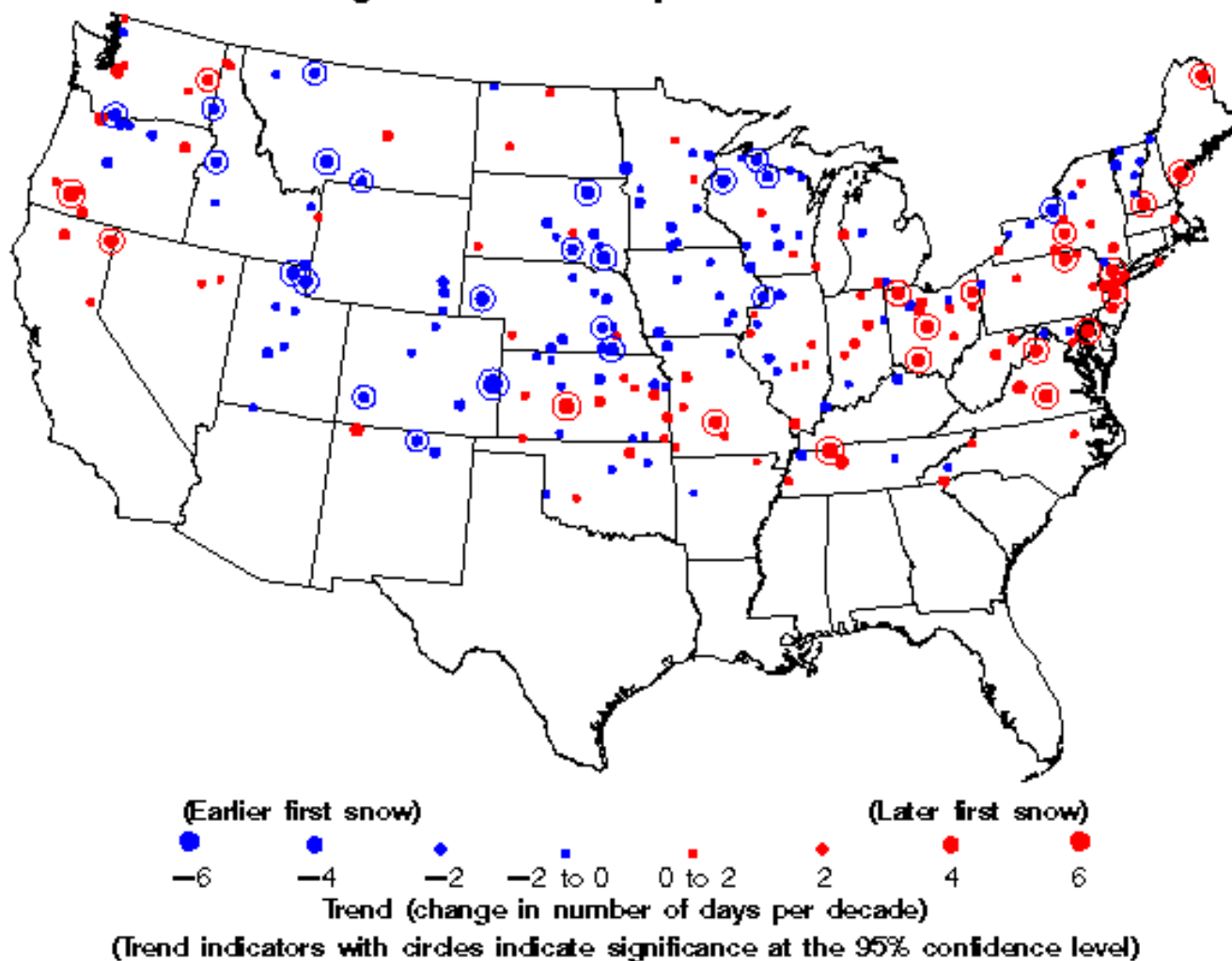
Trend (percent of normal snowfall over 1948/49–2000/01)

(Trend indicators with circles indicate significance at the 95% confidence level)

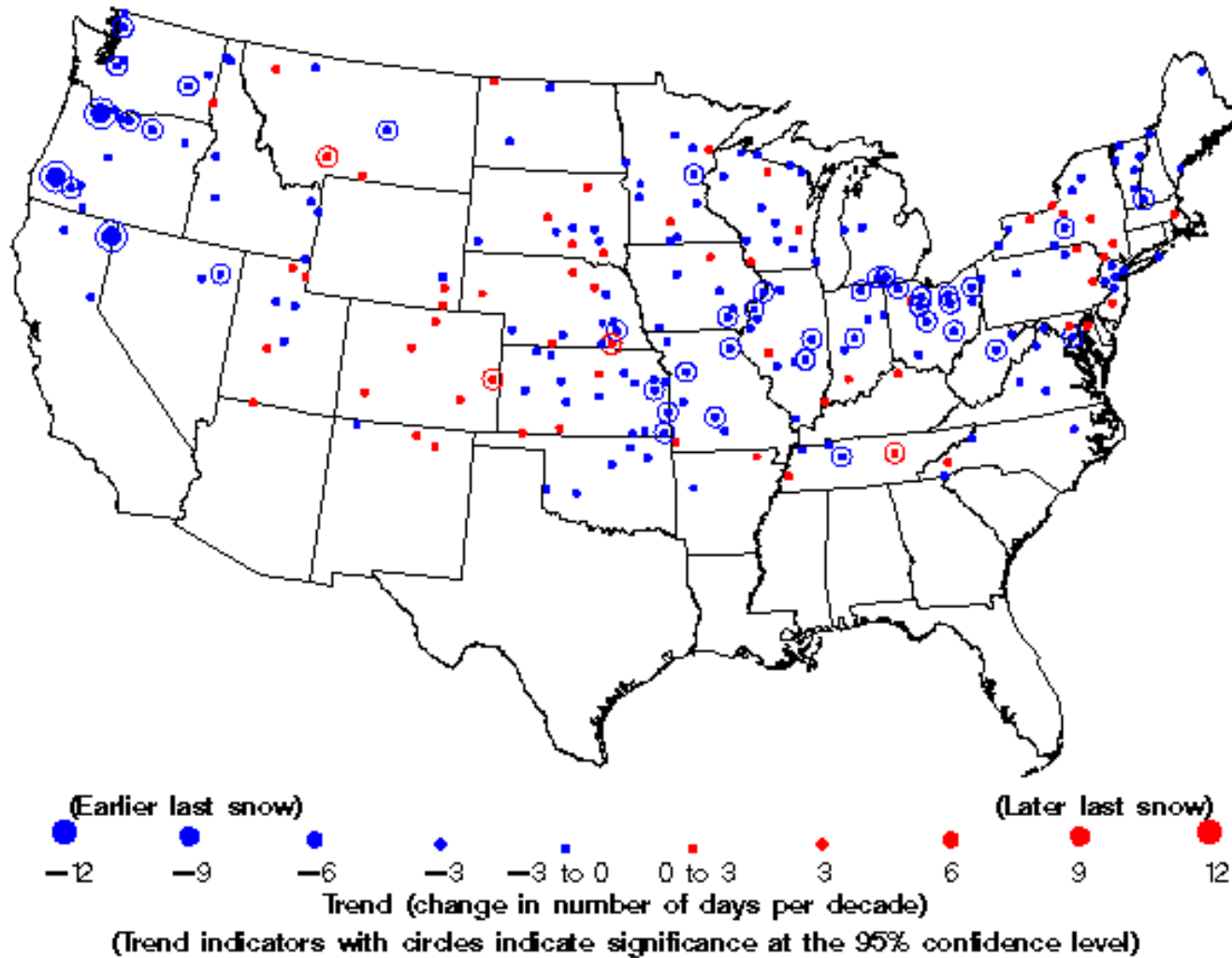
Trends in percent of annual precip from snowfall, 1948–2001



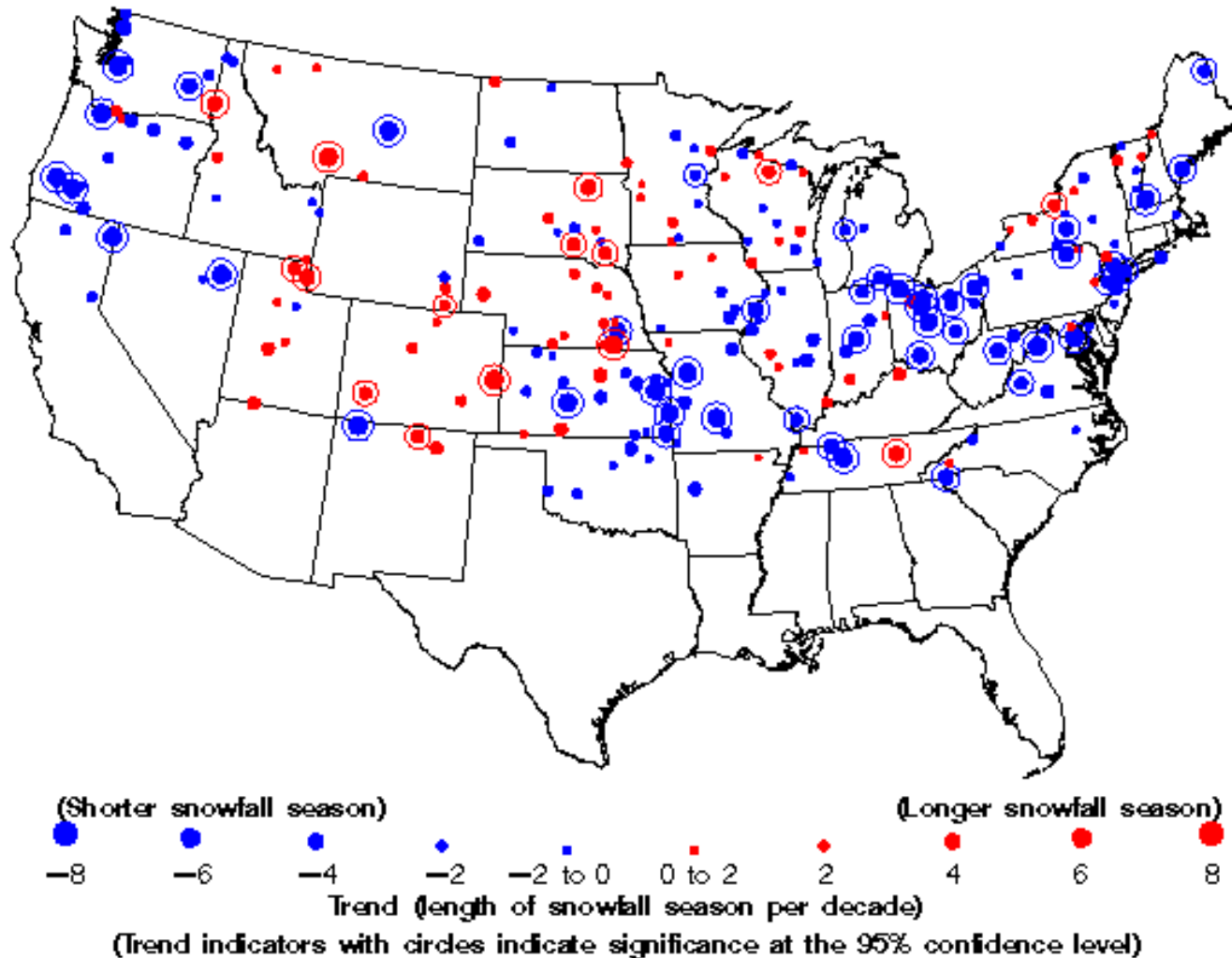
Change in the first day of the snowfall season



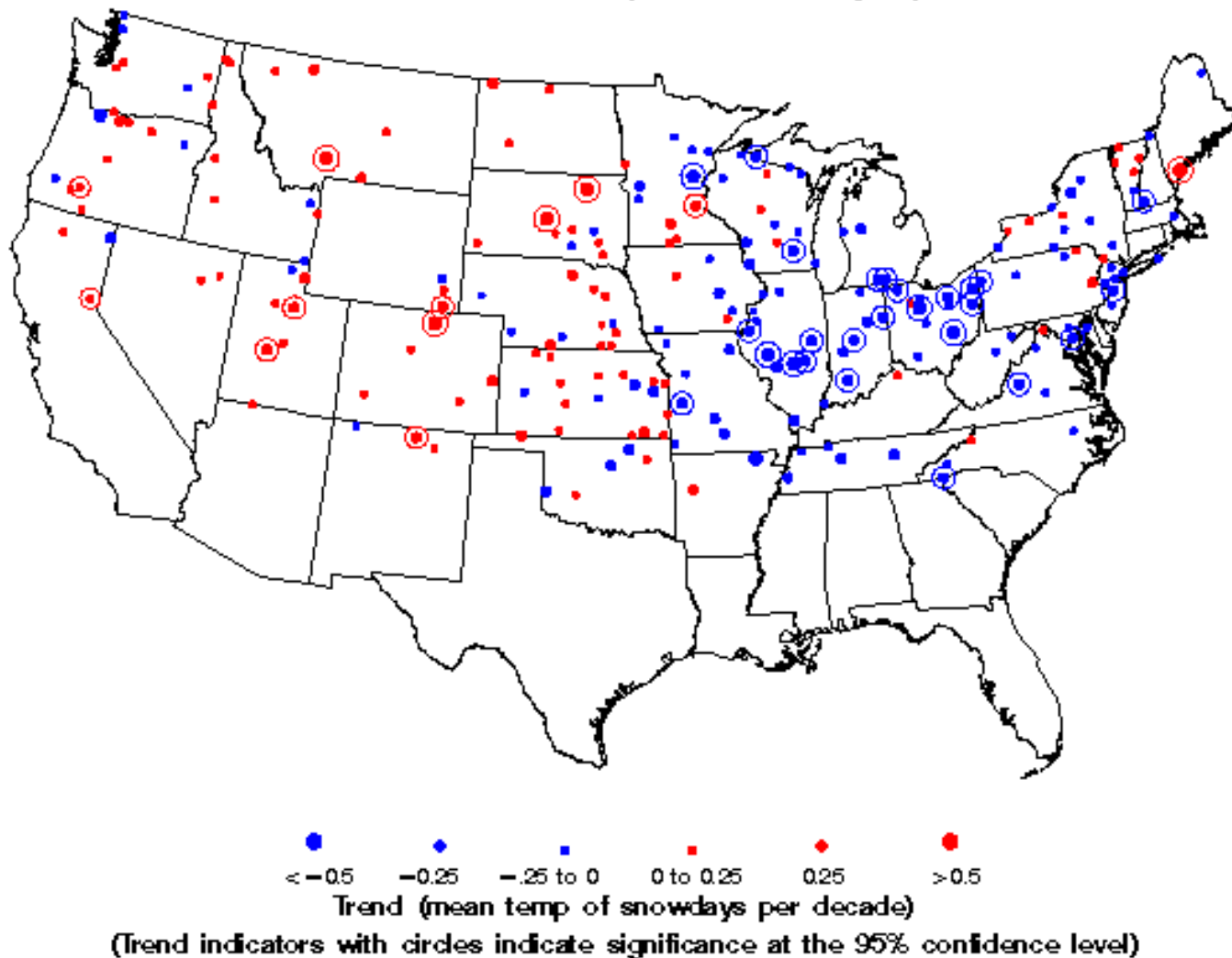
Change in the last day of the snowfall season



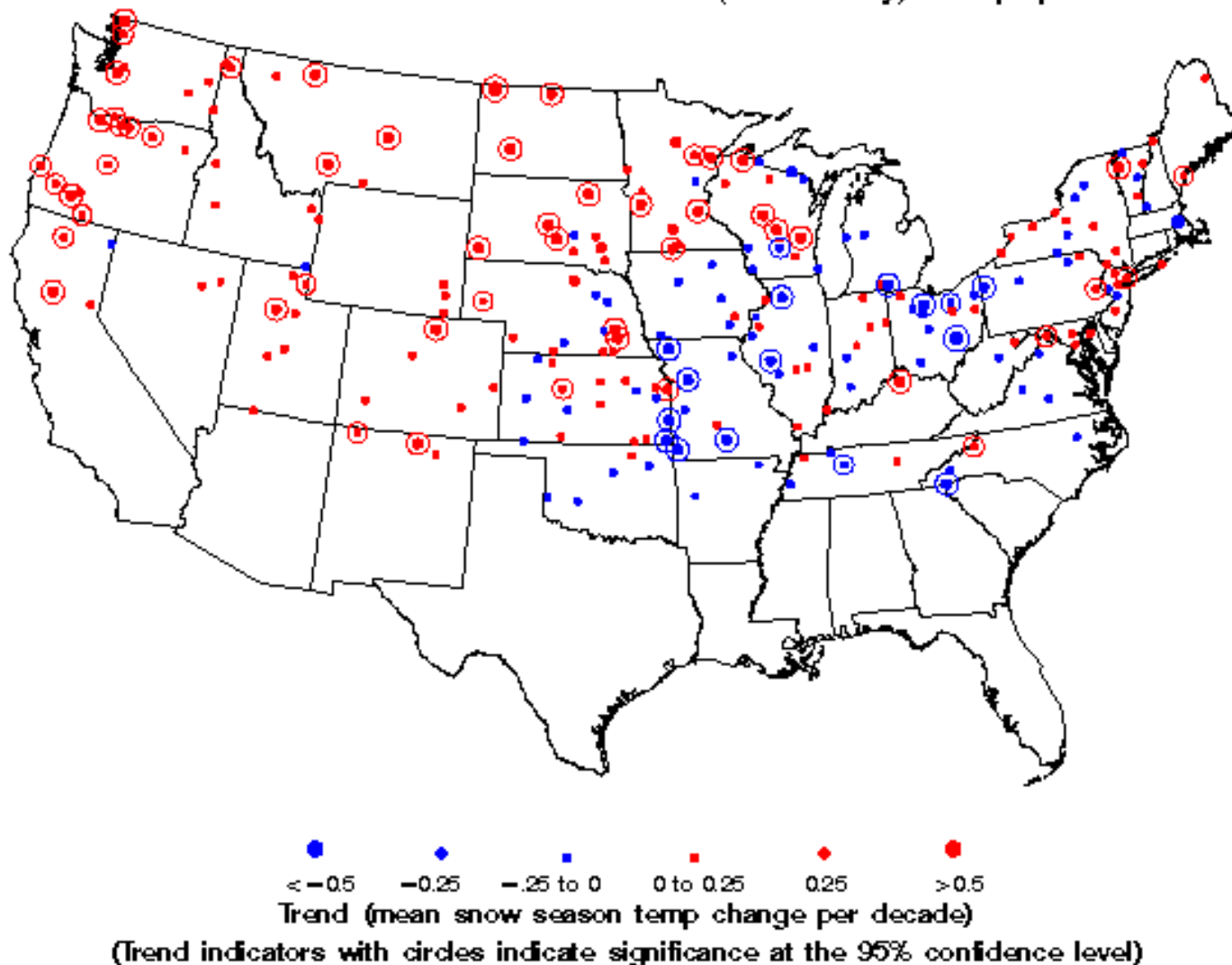
Change in the length of the snowfall season



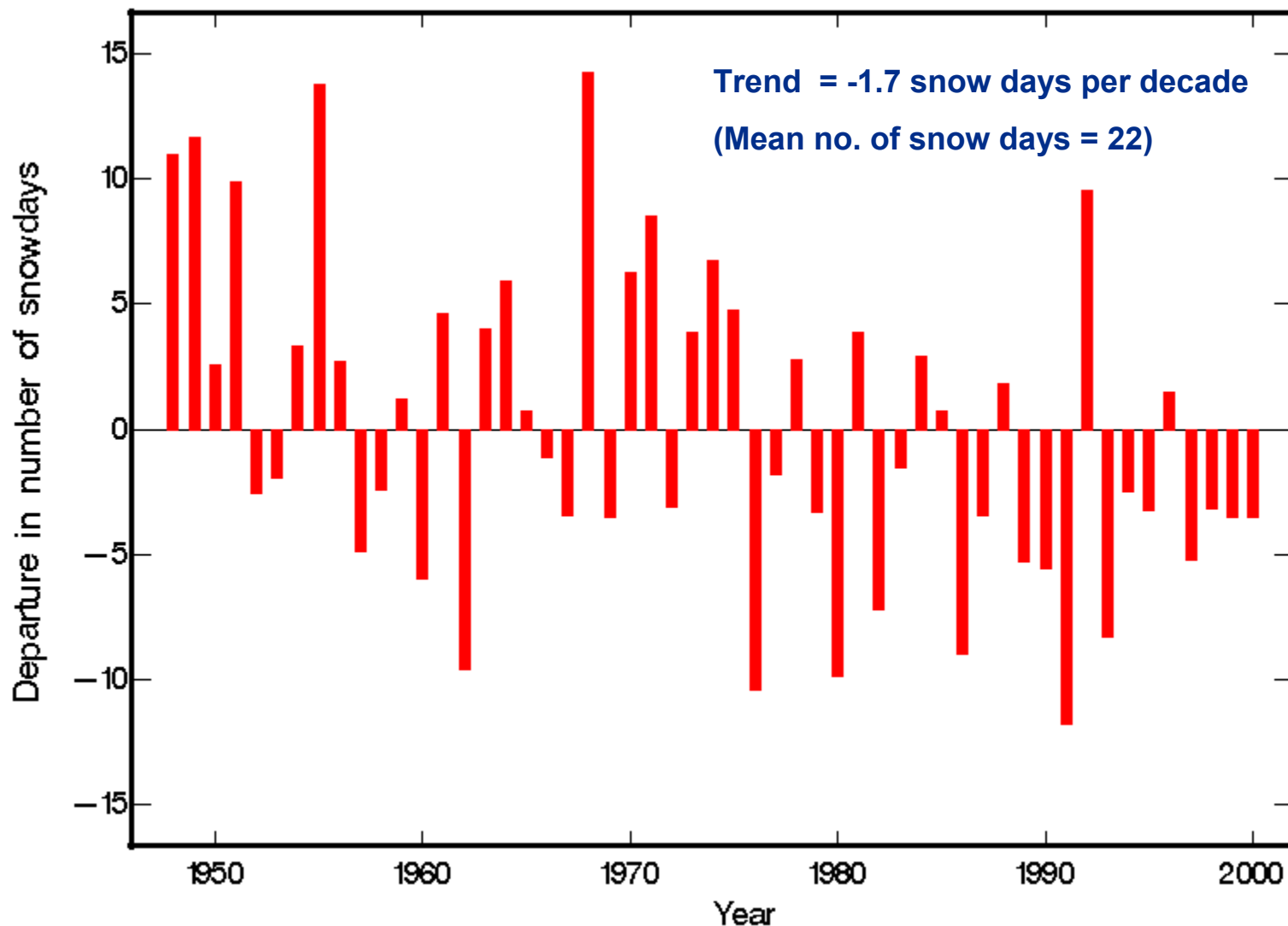
Trends in the mean temp of snowdays per decade



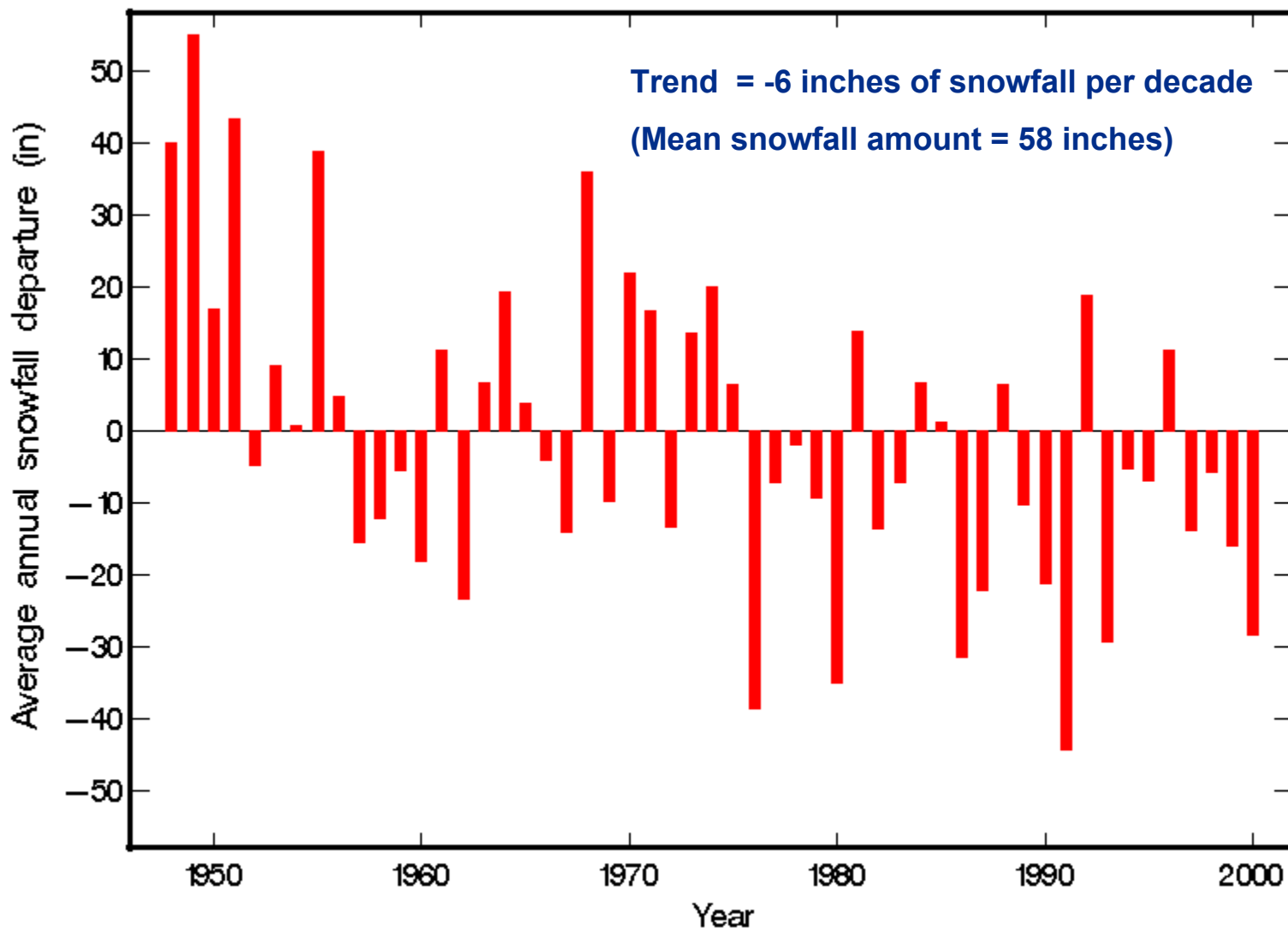
Trends in the mean snow season (Oct—May) temp per decade



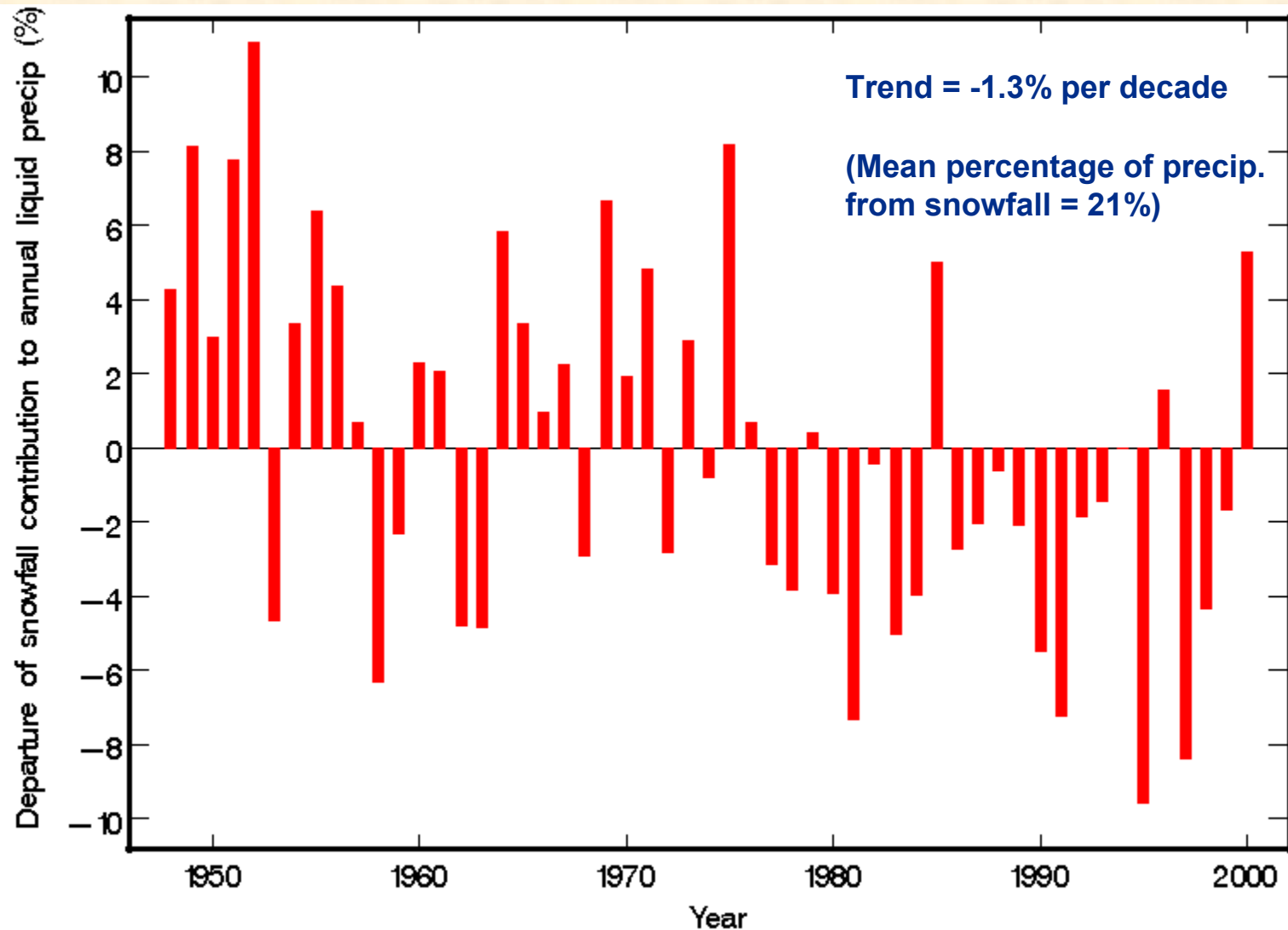
Departures in Oct–May snow days over Washington, Oregon, and Idaho, 1948/49 – 2000/01



Departures in Oct–May snowfall (in.) over Washington, Oregon, and Idaho, 1948/49 – 2000/01



Departures in annual percentage of precip. attributable to snowfall over Washington, Oregon, and Idaho, 1948/49 – 2000/01



weak in the Willows Mountains of northeastern Oregon, where McCabe and Deringer (2002) found that SWE varied fairly independently of the rest of the region. The

Trends in snow water equivalent in the Pacific Northwest and their climatic causes

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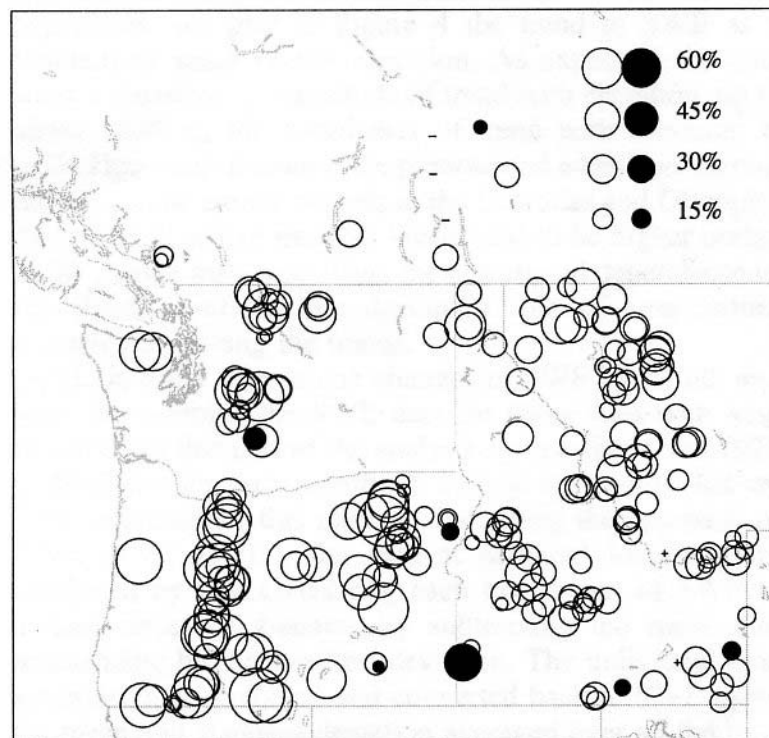
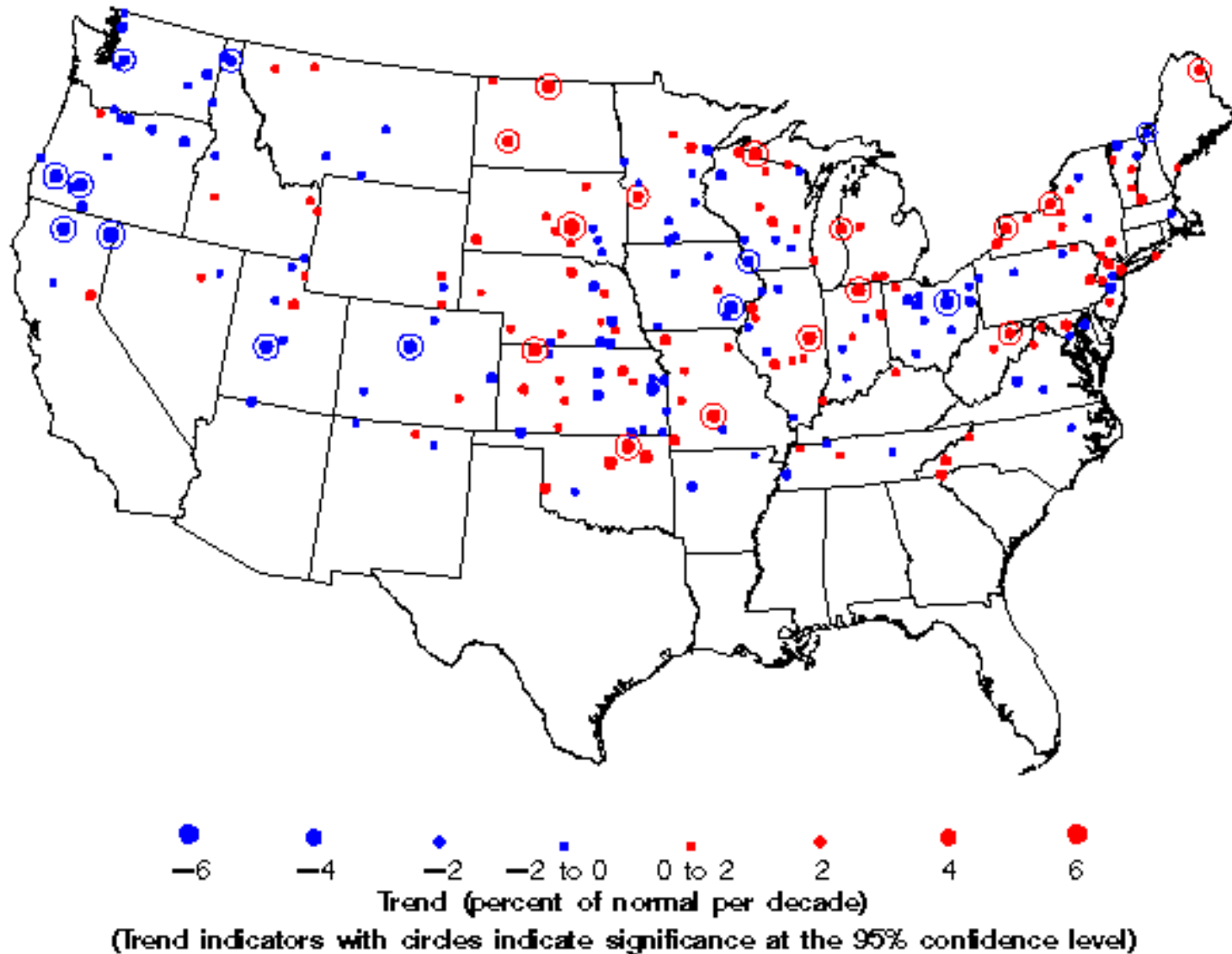
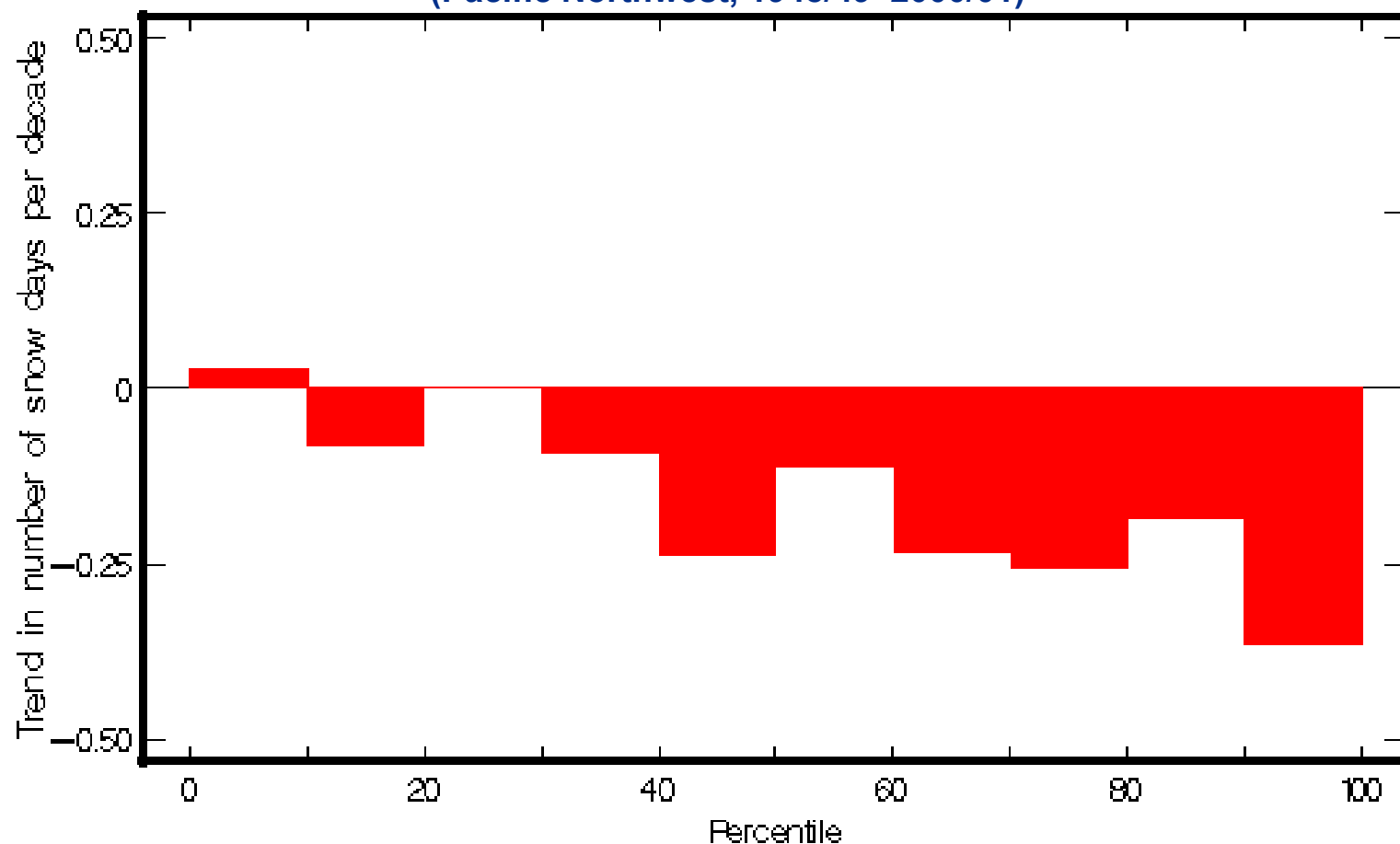


Figure 1. Linear trends, relative to starting value, in snow water equivalent (SWE) on April 1 over the period of record 1950–2000. Negative trends are shown as open circles, positive trends as solid circles; the magnitude of the trend is indicated by the area of the circle according to the legend. Trends less than 5% in absolute value are indicated by a + or – symbol.

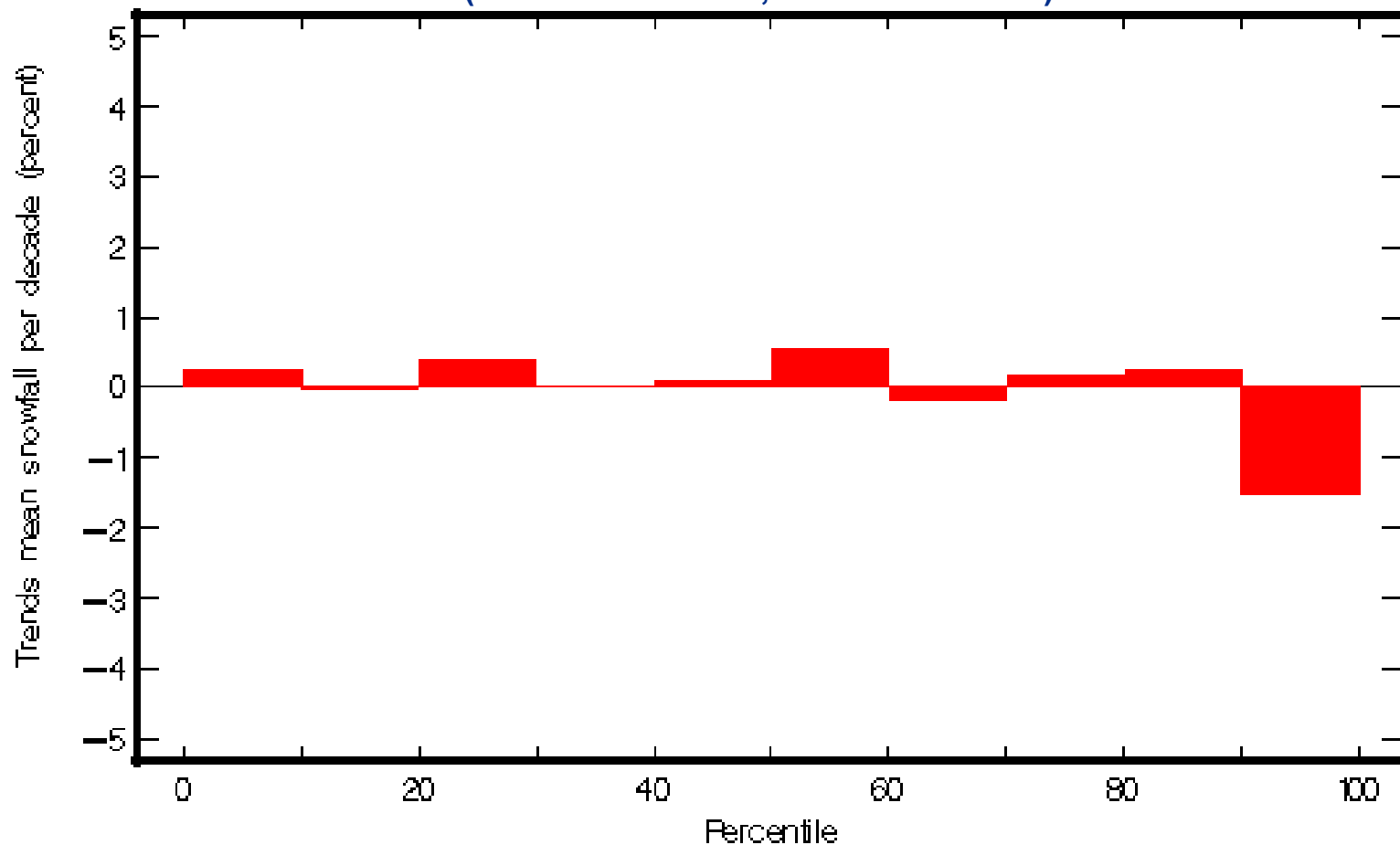
Trends in percent of seasonal snowfall from 90th percentile events



Trends in number of snow days within each event size percentile
(Pacific Northwest, 1948/49–2000/01)



Trends in seasonal snowfall per class interval
(Pacific Northwest, 1948/49–2000/01)



Results — *Snow Days*

Decreasing in the Pacific Northwest (PNW)—mainly over the Washington, Oregon, and Idaho (WOI) area. Trends of -3 to -4 days per decade.

Decreasing (generally) over an area from roughly Kansas eastward through New Jersey. Some stations at the rate of -2 to -3 days per decade.

Increasing over an area extending from roughly Colorado northeastward to Minnesota. Some stations at the rate of 2 to 3 days per decade.

Increasing to the lee of Lake Ontario (the well-known southeastern and eastern shore lake effect snowbelt areas). Rates of 2 to 3 days per decade.

These findings in the WOI area are consistent with the findings of Easterling (2002). He found that the ***annual number of frost days*** (defined as a day when the temperature dropped below 0°C) ***decreased by 2.6 days per decade in the WOI area***, and that the change in the ***frost-free portion of the year has increased by 4.1 days per decade*** (an increase of about 20 days in 50 years) over this same region. These changes would imply fewer days with temperatures cold enough to support snow and thus conditions that would favor more liquid precipitation events.

Trends in number of frost days — from Easterling (2002)

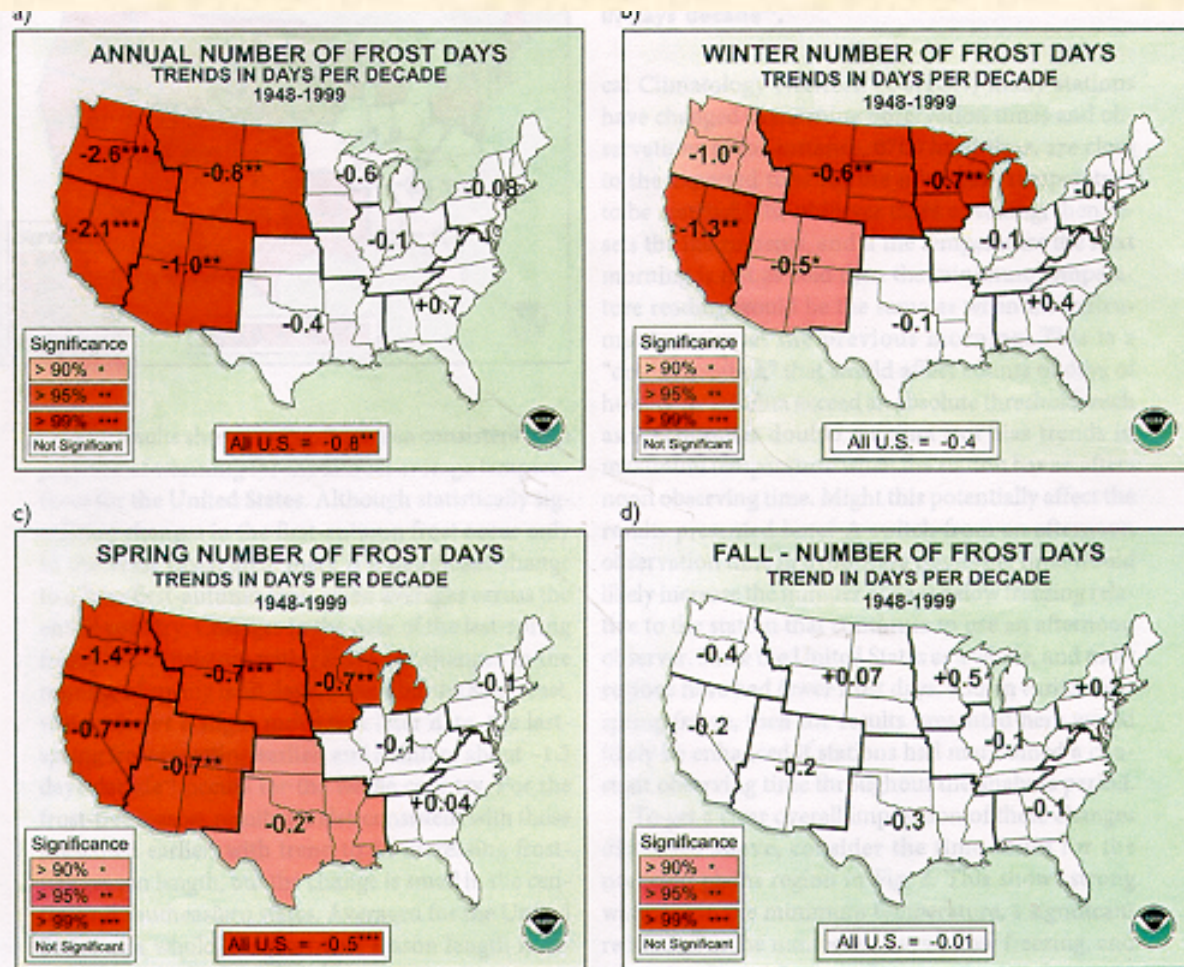


FIG. 1. Trends in number of frost days (days where the min temperature was below 0°C) in days decade⁻¹ for (a) annual, (b) winter, (c) spring, and (d) fall.

Results — *Snowfall*

Decreasing in the Pacific Northwest (PNW)—mainly over the Washington, Oregon, and Idaho (WOI) area. Trends of -3 to -9 inches per decade. Consistent with decreases found in snow days.

Increasing at a significant number of stations extending from roughly Colorado northeastward to Wisconsin. These stations have increased mainly from 3 to 6 inches per decade.

Increasing to the lee of Lake Ontario (the well-known southeastern and eastern shore lake effect snowbelt areas), with a hint of an increase at the eastern end of Lake Erie (examining more stations there would be useful). Increases on the order of 3 to 6 inches per decade.

Again, the WOI findings are consistent with those of Easterling (2002) showing a decreasing number of frost days (previous slide).

Results — *Percentage of annual precip. from snowfall*

Decreasing in the Pacific Northwest (PNW)—mainly over the Washington, Oregon, and Idaho (WOI) area. Trends of -2% to -3% per decade. Consistent with decreases found in snow days and snowfall.

Decreasing at scattered stations stretching from the Great Plains into parts of the Great Lakes states including Wisconsin, Michigan, and especially Ohio. Trends of generally -2% to -3% per decade.

No contiguous areas of the country show significant increases in the amount of annual precipitation resulting from snowfall.

Results — *Beginning, ending, and length of snowfall season*

The *first snowfall day* of the season is now occurring generally *later* over the eastern parts of the midwestern U.S. and most of the northeastern U.S. (about 10-20 days later in some locations over 1948–2000).

The *first snowfall day* is occurring generally *earlier* over the western midwestern states, the northern plains states, and parts of the Rocky Mtn. states (10-20 days earlier at many locations).

Over the Pacific Northwest there is a mixed signal, but most stations show signs of the *first snowfall day* coming *later*.

The *last snowfall day* of the season is occurring generally *earlier* over the midwestern states and the Pacific Northwest.

No region of the country shows signs of the *last snowfall day* trending toward a later date.

The *length of the snowfall season* is becoming *shorter* over a region extending from the central plains states, across the midwestern states, into parts of the northeastern U.S. It is also becoming shorter over Washington and Oregon.

Many stations scattered from the central Rocky Mtn. states across the northern plains states show evidence of a *longer snowfall season*.

Results — *Temperature trends as they relate to the snowfall season*

For the *snow season as a whole* (Oct–May), *mean daily temperature* has **warmed** over most of the United States from 1948/49–2000/01, however over parts of the midwestern states there has been some **cooling**.

Days with measurable snowfall across the midwestern states have shown a significant **cooling** trend from 1948/49–2000/01. Most of the rest of the country shows little evidence of temperature trends on snow days.

Results — *Changes in the percentile distribution of snowfall*

At this point we've focused attention on the Pacific Northwest due to its many internally-consistent changes relating to snowfall (fewer snow days, decreased snowfall, warmer temperatures, shorter snowfall season, etc.).

Changes within the highest snowfall percentiles show consistent evidence of fewer extreme snowfall events and a decreasing trend in the magnitude of the upper percentiles over 1948/49–2000/01.